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Argonne NATIONAL LABORATORY

Diesel Engine Underhood Thermal Analysis

Final CRADA Report

Nuclear Engineering Division

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Participants: Cummins, Inc., Automotive Customer Engine Division, Columbus, Indiana

September 1, 2007

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Non Proprietary

Final CRADA Report

Date: September 1, 2007

CRADA Number: 0501001

CRADA Title: Diesel Engine Underhood Thermal Analysis

CRADA Start/End Date: 09/2005 to 09/2007

Argonne Dollars: $600,000

Participant Dollars: $600,000

Argonne PI: Tanju Sofu

Participant(s):

Cummins, Inc. $600,000
Name Participant Dollars

Automotive Customer Engine Division, Columbus, Indiana
Complete Address

_____ $_____
Name Participant Dollars

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Complete Address

_____ $_____
Name Participant Dollars

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Complete Address

DOE Program Manager: Sid Diamond

Summary of Major Accomplishments:

An assessment of 1-D and 3-D thermo-fluid simulation methods was performed to predict underhood temperature distributions in a prototypical diesel heavy-duty truck engine compartment. The Participant conducted full-vehicle dynamometer tests to generate data for validation. The Contractor developed analytical models and conducted integrated engine thermal-systems simulations using 1-D thermal-fluid network flow model to account for overall energy balance, and computational fluid dynamics (CFD) model to resolve the 3-D flow field component temperature distributions.

Summary of Technology Transfer Benefits to Industry:

The participant adopted the novel, coupled 1-D and 3-D thermo-fluid simulation method developed as part of this CRADA for their continuing heavy-vehicle thermal systems optimizations.

Other Information/Results: (Papers, Inventions, Software, etc.)

Conference papers, journal articles, and contribution to an edited book.

Abstract

To gain insight into the underhood thermal control of a heavy vehicle (e.g., truck), a computer model was developed at Argonne National Laboratory (ANL) under the CRADA work with Cummins Inc. Using one-dimensional (1-D) and three-dimensional (3-D) simulation methods, we performed the analyses designed to evaluate underhood cooling performance. The analytical work involved development, validation, and application of these methods to optimize the thermal control in the testing vehicle. A 1-D thermal-fluid network model was developed to account for overall energy balance and to simulate ventilation and hydraulic system response. This model was used in conjunction with a 3-D computational fluid dynamics (CFD) model used to calculate the ventilation air temperatures and the distributed surface heat transfer.

By taking into account the ventilation air and coolant heat transport, radiator performance, exhaust gas recirculation (EGR) efficiency, and cabin heater operation, the integrated computer model provides an opportunity to understand the combined effects of the engine cooling systems on underhood thermal control. The developed simulation package benefits the development of the vehicle underhood thermal management system by reducing the design cycle time and cost and by reducing the engine testing when installed into different truck configurations.

Summary

Heavy vehicles present common underhood thermal control challenges: restrictive enclosures and ever-increasing variety of heat sources. With typical underhood temperatures in a separated engine compartment varying from 50 to 200°C, the specific issues for underhood temperature control are the ventilation air flow requirements and the coolant system designs for engine cooling performance. Beside these, heavy vehicles present rather unique additional underhood thermal control and engine cooling issues such as:

- thermal performance of the air-side system (radiator and fan),
- thermal efficiency of exhaust gas recirculation (EGR) system, and
- cabin heat exchange.

Because high underhood temperatures can reduce component durability and life, the assessment of component temperatures is an important element of design. These assessments are typically made during a conventional cooling test; however, the measurement of many component temperatures for various configurations is not always feasible. Furthermore, the cooling test typically occurs during the later stages of the development cycle, when major component relocation is not practical. Therefore, to identify possible hot spots and assure adequate air cooling, it is desirable to have an analytical capability to help us understand the thermal conditions inside the separated engine component.

To address these issues, a Cooperative Research and Development Agreement (CRADA) was executed between Argonne National Laboratory (ANL) and Cummins Inc. to measure and analyze engine cooling system and underhood ventilation air flow. The experimental effort by the Cummins team focused on conducting tests with controlled ventilation air flow rates at wind tunnel inlet and with controlled coolant temperature and flow rate at coolant pump to estimate the cooling needs for an enclosed truck engine.

The purpose of the analytical studies by the ANL team (with modeling support from FLUENT Inc. and FLOWMASTER International) was to assess the various simulation methods that could be used to predict underhood ventilation air temperatures and engine component surface temperatures. The work involved development and validation of combined 1-D and 3-D simulation models of the Cummins ISX diesel engine (rated at 500 ~ 565 HP) to evaluate engine cooling system. Although the separated cooling system compartments are unique to trucks, the Cummins tests and the ANL analyses provide an opportunity to understand the combined effect of coolant cooling and air cooling on engine performance for a wide range of heavy vehicles.

Computer simulation is quickly becoming an established and integral part of the design cycle for automotive manufacturers worldwide. Computer simulation benefits vehicle thermal management system designs by reducing design cycle time and cost. Its ability to quickly model different designs and conditions reduces the need for vehicle testing, which is time consuming and expensive, and enables engineers to produce more robust designs. Simulation can also improve an engineer's understanding of the vehicle's thermal management system and the interactions of the different subsystems involved. While designers understand the performance of individual components with which they are personally involved, it is often difficult to understand how a collection of those components performs when assembled as a complete system and interacting with other systems.

FLUENT is a three-dimensional computational fluid dynamics (CFD) solver which allows engineers to import the complicated underhood geometry and calculate the complex flows typical for vehicle underhood thermal analysis. FLUENT solvers are based on the finite volume method with domain discretized into a finite set of volumes or cells, and with general conservation equations for mass, momentum, energy, and turbulence. With multiple solver options combined with a convergence-enhancing multigrid method, FLUENT provides an efficient and accurate solution for underhood thermal analysis.

FLOWMASTER is a one-dimensional fluid flow analysis program and allows engineers to graphically model complete fluid systems to predict pressure, temperature, heat flow, and fluid flow distribution in their systems. The physical basis of FLOWMASTER is built on empirical correlations as well as analytical conservation equations for mass, momentum, and energy. An extensive database is included with the software to describe the components of a system, such as pipes, pumps, heat exchangers, heat sources, and flow sources, etc. The user can also incorporate the performance characteristics of other components into the database.

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